EFFECT OF FROST ON CONCRETE

BY
W. S. OEHNE
M. MALZEN
W. R. SWANSON

ARMOUR INSTITUTE OF TECHNOLOGY

1912

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Effect of frost on concrete

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THE EFFECT OF FROST ON CONCRETE.

A THESIS.

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FOR THE DEGREE OF BACHELOR OF SCIENCE IN CIVIL ENGINEERING, HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

CIVIL ENGINEERING.

MAY 25, 1912.

Alfred E. Phillips
Prof Civil Engineering

H. M. Raymond
Dean of Eng. Studies

L. C. Monin.
Dean of Cult. Studies.

THE EFFECT OF FROST ON CONCRETE.

In selecting the subject of this thesis, the object was to enter a field which had not already been too greatly drawn upon. Investigation showed that the effects of frost upon concrete were not very generally tabulated, and that not much data was available on this subject. It was therefore chosen.

The object pf the work was to make a series of cubes of concrete under varying conditions of temperature, and to compare the strengths of these cubes with those of a series of standard cubes which had been prepared under ideal conditions.

The work was divided into three sections, first, preliminary work, in which the percentages of voids in the sand and stone were determined, and also, in which proportions the concrete would be the densest. The second section of the work consisted of the actual making of cubes and cylinders, with the densest mixture of concrete. The third and final division of the work consisted of testing the aforesaid cubes and cylinders in a testing machine, to find their crushing strength.

This percentage of voids in the sand and stone was found as follows: A pail was first weighed, and afterward filled with stone. It was then weighed again. Then water was poured into the pailful of stone until filled, when it was

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weighed again. Then a bucketful of water was weighed alone. The ratio of the weight of water required to fill the voids, to the weight of a pail of water multiplied by 100 gave the percentage of voids in the stone.

Weight of pail	2.80#
" of stone and pail	37.25#
" of stone, pail and water	49.00#

Weight of pail of water	27.93#
" " empty pail	2.80#
Weight of water	25.13#

Weight of water in voids 49 - 37.25 = 11.75#

% of voids 11.75 x 100/25.13 = 46.77%

The percentage of voids in the sand was found in exactly the same manner as above, the data being as follows:-

Wt. of sand, water and pail	59.32#
" " " and pail	42.00#
Wt. of water	17.32#

Wt. of water in pailful 25.13#

% voids 17.32 x 100/25.13 = 68.92%

In the determination of the densest concrete, three mixtures were tried, namely: 1: 1: 2, 1: 2: 4 and 1:3:5½. The

The total weight of the concrete was kept constant, as was the weight of cement in each case. Different weights of sand and stone were used with the different mixtures. The weight of water used in all cases was 30% of the weight of the cement. The materials were well mixed and rammed into a cylindrical bucket of which the diameter and height were known. Then, measuring the height to which the concrete rose in the buckets, its volume was readily computed. The weight being constant, it was therefore evident that the concrete which occupied the least volume was the densest. This was found to be the 1:2:4 mixture.

The actual work of making the cubes to be tested was then taken up. The first batch, known as A and A, consisted of ten ordinary 6 inch cubes of 1:2:4 concrete. The cubes were mixed indoors, the materials being at ordinary room heat or about 65° F. The lot designated by the letter A was placed outdoors for seven days, and then placed indoors for seven days, being then tested. The average temperature for the period was 29°, the maximum being 34° and the minimum 24°.

The other lot of five, namely A_1, was placed outdoors for seven days, then indoors for seven days. At the end of this time they were again placed outside for a week, and then indoors for a week, making a total of four weeks. They were then tested. From tables A and A_1, it will be seen

that the average unit crushing strength of the batch four weeks old was greater than that of Lot A. This greater strength was probably due to the greater age of the cubes, and to nothing else. It seems that alternately frost and heat had no effect upon the cubes after the concrete was once set.

In the second lot of cubes heated materials were used. The mixture as before was 1:2:4, and the concrete was mixed indoors, 10 cubes being made. The sand and stone were heated to 78° F, while the water was 150° F. Five of the cubes were left indoors for a week, then taken outside for a week, and then tested. This lot was known as B.

The other lot of five cubes, known asB, were alternated between indoors and outdoors for four weeks, at intervals of one week.

The results of the tests of these lots are given in tables B and B_1. As in A and A_1, the older concrete was the stronger, the alternation from hot to cold, apparently having no effect upon the strength.

The next two lots mixed, known as C and C, were mixed of unheated materials and out of doors. The temperature of sand and stone was 35° , while that of the water was 45° .

Lot C, consisting of five cubes, was treated exactly as A and B had been. Lot C_1 was treated as A_1 and B_1 had a

been.

Reference to tables C and C_1 still shows the strength of the older concrete to be the greater.

In the next lots, namely D and D_1, the concrete was made of heated material mixed out of doors. Each batch consisted of five cubes. Lot D was treated as A, B and C had been, and lot D_1 was treated as A_1, B_1, and C_1 had been. The The results are shown tabulated in tables D and D_1.

The next work taken up was the preparation of a set of standards under ideal conditions. Two batches of five cubes each were made and designated as E and E_1. Heated materials were used, and the concrete was mixed indoors. The mixture was 1:2:4, being just wet enough to be easily tamped. Lot E was left indoors two weeks, while lot E_1 was left indoors for four weeks. The average temperature during this period was 65° F. or about ordinary room temperature.

As tables E and E_1 show, the strength of this concrete was rather great.

One of the cylinders was also made from this batch, but it was allowed to age. Therefore the results of the tests appear later on.

Lots F and F_1 were also standards made of unheated materials, mixed indoors. They were treated the same as E and E_1 and tested.

A cylinder was also made from this batch.

Reference to the tabulated results will show the detrimental effect of frost upon the concrete. Series E, mixed under ideal conditions, that is with heated materials and indoors, shows a much greater strength than C, which was mixed under the worst of conditions, and allowed to freeze and thaw alternately. None of the cubes which were exposed to the action of the cold approached the standards in strength. Those mixed with heated materials showed better results than those with unheated.

Thus we see that concrete made of warm materials, being mixed and cured in a warm atmosphere, far exceed almost any other in strength. Cold materials, mixed and cured in a warm place, form a concrete not much below the first in strength.

Concrete formed of heated materials mixed in a warm atmosphere but exposed to the action of frost come next in strength.

Mixed- Feb. 15 1912

Tested- Mar. 1 1912

Table A.

NO.	Area □"	Weight #	Total Load	lbs. sq. in.
1	36	18.71	41150	1143.
2	36	18.34	41450	1151
3	35.5	18.60	32000	902
4	36.4	18.95	43210	1187
5	36	18.30	35100	975
Average		18.56.	38582	1059

Mixed- Feb 15, 1912

Tested- Mar. 14, 1912.

Table A1.

NO.	Area □"	Weight #	Total Load.	lbs. sq. in.
1	35.7	17.9	50110	1404
2	36	18.54	58150	1615
3	36	18.92	45470	1263
4	36.3	19.07	49580	1366
5	36	18.86	51240	1423
Average		18.65	50910	1416

Mixed- Feb. 23, 1912.

Tested- Mar 8, 1912

Table B

NO.	Area	Weight	Total Load	lbs. sq. in.
1	36	17.96	41120	1142
2	36	17.27	39150	1088
3	36	17.44	33190	922
4	36.7	18.25	45260	1159
5	35.6	18.70	50250	1412
Average		17.72	42194	1145

Mixed Feb. 23, 1912

Tested Mar 23, 1912

Table B1

NO.	Area	Weight	Total Load	lbs. sq. in.
1	36	17.91	51710	1436
2	36	18.06	49980	1388
3	35.7	17.76	48800	1367
4	36	17.83	59100	1642
5	36	18.13	62200	1728
Average		17.94	54358	1512

Mixed- Feb. 26, 1912

Tested- Mar. 11, 1912

Table C

NO.	Area.	Weight	Total Load	lbs. sq. in.
1	36	17.93.	26030	723
2	36	17.84	21990	611
3	35.4	18.62	21810	616
4	35.7	18.43.	21550	603
5	36	18.26	20210	561
Average		18.22	22318	623

Mixed- Feb. 26 1912

Tested- Mar. 25, 1912

Table C_1

NO.	Area	Weight	Total Load	lbs. sq. in
1	36	17.17	23190	644
2	35.7	18.12	31100	864
3	36	17.62	31210	866
4	36	17.91	29150	809
5	36	18.09	27900	778
Average		17.78	28510	792

Mixed- Feb. 28, 1912

Tested- Mar. 15, 1912

Table D

NO.	Area	Weight	Total Load	lbs. sq. in
1	36	17.60	30700	853
2	36	18.02	34170	950
3	36	18.12	31010	861
4	36.2	17.88	29310	810
5	36	17.94	31720	881
Arerage		17.91	31382	871

Mixed- Feb. 28, 1912

Tested Mar. 27 1912

Table D1

NO.	Area	Weight	Total Load	lbs. sq. in
1	36.3	17.50	40110	1105
2	36	18.10	41110	1142
3	36	18.21	40050	1112
4	36	17.64	44620	1240
5	36	17.76	47830	1330
Arerage		17.84	42745	1186

Mixed- Mar. 25, 1912

Tested- Apr. 8, 1912

Table E

NO.	Area	Weight	Total Load	lbs. sq. in.
1	36	17.92	64110	1781
2	36	18.21	68190	1894
3	35.4	18.34	65110	1839
4	36	18.16	64220	1771
5	36.2	17.82	63440	1753
Average		18.09	65016	1807

Mixed- Mar 25, 1912.

Tested- Apr 22, 1912

Table E1

NO.	Area	Weight	Total Load.	lbs. sq. in.
1	36	18.20	70150	1949
2	36	18.10	68240	1895
3	36.6	17.94	74240	2028
4	36.5	18.14	72120	1976
5	36	17.85	66980	1861
Average.		18.05	70346	1942

Mixed- Mar. 18, 1912

Tested- Apr. 1, 1912

Table F

NO.	Area	Weight	Total Load	lbs. sq. in.
1	36	17.64	65210	1811
2	36	18.31	68210	1895
3	36	18.12	64150	1782
4	36	17.79	56110	1558
5	35.7	17.94	66410	1804
Average		17.96	64018	1770

Mixed- Mar. 18, 1912

Tested- Apr. 15, 1912

Table F1

NO.	Area	Weight	Total Load	lbs. sq. in.
1	35.9	17.91	62470	1740
2	36	17.98	69240	1923
3	36	18.21	73180	2033
4	36	18.20	65960	1832
5	36.2	17.92	70970	1684
Average		18.04	68364	1802

Month	Day.	Maximum	Minimum.	Average
		Temperature. F°		
February.	15	30	15	22.5
	16	33	20	24.5
	17	48	29	33.5
	18	50	40	45.0
	19	41	34	37.5
	20	32	29	30.5
	21	24	22	23.0
	22	25	15	20.0
	23	40	23	31.5
	24	51	22	36.5
	25	30	34	32.0
	26	22	36	29.0
	27	32	14	23.0
	28	22	10	16.0
	29.	29	12	20.5
March	1	31	9	20.0
	2	28	14	21.0
	3	22	14	18.0
	4	23	15	19.0
	5	22	15	18.5
	6	26	15	20.5
	7	32	22	27.0
	8	12	34	23.0
	9	22	36	29.0
	10	40	25	32.5
	11	36	25	30.5
	12	30	27	28.5
	13	31	26	28.5
	14	32	28	30.0
	15	34	29	31.5
	16	38	15	26.5
	17	44	32	38.0
	18	40	31	35.5
	19	45	28	36.5
	20	24	15	19.5
	21	31	25	28.0
	22	34	24	29.0
	23	36	21	28.5
	24	29	22	25.5
	25	34	24	29.0
	26	45	31	38.0
	27	48	32	40.0

Indoor temperature constant at 70° F

TEST OF SHORT COLUMNS.

Description of Apparatus used in Measuring the Deflection.

Two wrought iron rings were made of one inch by one half inch material. The ring was made to a diameter of about nine inches. At quarter points on the ring set screws were placed, as shown on Fig. B (AA) Plate V. A smaller size set screw was placed on the underneath surface of the upper ring (Shown as B in Fig. B). Then a point was located on the upper side of the lower ring in plumb with the small screw. Micrometer was placed between these two points and the length measured at each increase in the load.

Testing of Column A.

Column A had a length of 18 inches and a diameter of 6. The area of the compression surface was fifty and three tenths square inches. The column was thirty five days old at the time of testing.

Loads were applied in increments of about twelve hundred pounds. The column stood up to the test until the breaking load was reached, seventy-nine thousand, five hundred and ten pounds. No flaking occurred until the final load. The failure was characteristic of concrete and a sketch of the failure is shown in Fig. A Plate V. The characteristic curves

for this column are shown on Plate VI. The ordinates of the points plotted represent the stress per square fouhd by dividingthe load as recorded in table on Plates I and II, by fifty and three tenths the compression area. The absessas are the strains found by dividing the total lineal distortion in inches by the effective length, eleven inches.

Column B failed at a much lower stress. At 28,480 pounds load flaking occurred near the upper surface. The fact that the column failed at such a low stress as compared with column A was probably due to the column being eccentrically located with respect to the pressure head of the machine.

Plates III and IV refer to the results of the test on column B and Plate VIII shows the characteristic curves.

TEST OF SHORT COLUMNS

MICROMETER READINGS		DISTORTION IN INCHES		STRAIN IN INCHES PER LIN. INCH		LOAD	
R	L	R	L	R	L	TOTAL	LB.PER SQ.IN.
.834	.979	0	0	0	0	0	0
.834	.978	.000	.001	0	.0001	1220	24.25
.833	.977	.001	.002	.0001	.00018	2360	46.9
.833	.977	.001	.002	.0001	.00018	3680	73.1
.831	.978	.003	.001	.000273	.0001	5160	102
.833	.978	.001	.001	.0001	.0001	6980	140
.833	.980	.001	-.001	.0001	-.0001	8580	170
.833	.980	.001	-.001	.0001	-.0001	10210	203
833	980	.001	-.001	.0001	-.0001	11450	227
.833	.979	.001	.000	.0001	.0000	13140	261
.832	.978	.002	.001	.00018	.0001	14610	321
.833	.978	.001	.001	.0001	.0001	16150	353
.832	.978	.002	.001	.00018	.0001	17770	387
.831	.978	.003	.001	.000273	.0001	19450	423
.831	.980	.003	-.001	.000273	-.0001	21290	456
.831	.978	.003	.001	.000273	.0001	22930	493
.832	.978	.002	.001	.00018	.0001	24820	533
.831	.978	.003	.001	.000273	.0001	26800	567
.830	.977	.004	.002	.000363	.00018	28510	603
.831	.974	.003	.005	000273	.000455	30320	636
.830	.974	.004	.005	.000363	.000455	32000	680
.830	.972	.004	.007	.000363	.00064	34020	713
.829	.970	.005	.009	.000455	.00082	35900	750
.830	.970	.004	.009	.000364	.00082	37770	786
.830	.970	.004	.009	000364	.00082	39520	823
.830	969	.004	.010	.000364	.00091	41400	850
.830	.970	.004	009	.000364	.00082	42740	880

PLATE II

TEST OF SHORT COLUMNS

MICROMETER READINGS		DISTORTION IN INCHES		STRAIN IN INCHES PER LIN.IN		LOAD	
R	L	R	L	R	L	TOTAL	LB.PER SQ.IN.
.830	.970	.004	.009	.000364	00082	44140	907
.829	.970	.005	.009	.000455	.00082	45610	936
.829	.970	.005	.009	.00455	.00082	47090	965
.828	.970	.006	.009	.00055	.00082	48550	1000
.828	.970	.006	.009	.00055	.00082	50140	1030
.828	.970	.006	.009	.00055	00082	51700	1060
.828	.970	.006	.009	.00055	.00082	53400	1090
.828	969	.006	.010	.00055	.00091	54930	1127
.828	.969	.006	.010	.00055	.00091	56680	1160
.828	.968	.006	.011	.00055	.0010	58390	1191
827	.968	.007	.011	.00064	.0010	59900	1222
827	.968	.007	011	.00064	.0010	61620	1250
.827	.967	.007	.012	.00064	.0011	63460	1300
.826	.966	.008	013	00073	.0012	64900	1322
.826	.966	.008	.013	00073	.0012	66500	1360
.826	.964	.008	.015	.00073	.0014	68290	1390
.826	.963	.008	.016	00073	.0015	69800	1416
.826	.962	.008	.017	.00073	.00164	71290	1450
825	960	.009	.019	00082	.00173	72980	1482
824	.957	.010	.022	.00091	.0020	74590	1516
824	.956	.010	.023	.00091	.0021	76230	1545
824	.951	.010	028	.00091	.00264	77690	1554
.824	.948	.010	.030	.00091	.00272	78730	1565
.824	.923	.010	.055	.00091	.0050	79510	1600

TEST OF SHORT COLUMNS

MICROMETER READINGS		DISTORTION IN INCHES		STRAIN IN INCHES PER LIN. IN.		LOAD	
R	L	R	L	R	L	TOTAL	LB. PER SQ. IN.
.891	.970	0	0	0	0	0	0
.890	.970	.001	.000	.0001	.000	2210	43.9
.890	.970	.001	.000	.0001	.000	3560	70.2
.893	.963	002	.007	.00018	.00064	4840	96.2
.897	963	.006	.007	.00055	.00064	6510	109.5
.901	959	.010	0.011	.00091	.001	8880	160.6
.903	.960	.012	.010	.0011	.00091	9750	193.8
.900	957	.009	.013	00082	.0012	11480	228.2
.901	.957	.010	.013	.00091	.0012	13150	241.3
.897	.953	.006	.017	.00055	.0016	14570	289.6
.898	.951	.007	.019	.00064	.00173	15800	312.1
.897	.951	.006	.019	.00055	.00173	16120	320.1
.897	.951	006	.019	.00055	.00173	17880	355.8
.897	949	006	.021	.00055	.00191	18790	373.5
.894	.949	.003	.021	.000273	.00191	19850	393.8
.892	.948	.001	.022	.0001	.002	20710	4119
.892	.947	.001	.023	.0001	.0021	22070	438.9
.892	.948	001	.022	.0001	.002	23040	458
.891	.946	.000	.024	.000	.0022	24270	482.5
.891	.946	.000	.024	.000	.0022	25420	505.3
.890	.943	.001	.027	.0001	.00255	26660	530
.889	.945	.002	.025	.00018	.0024	27320	543
.889	.943	.002	.027	.00018	.00255	28480	566.2
.887	.941	.004	.029	.00036	.00273	29170	580
.885	.941	.006	.029	.00055	.00273	30210	600.6
.882	.938	.009	.032	.00082	.00391	31260	621.2
881	.937	.010	.033	00091	.00391	32270	651.5

TEST OF SHORT COLUMNS

MICROMETER READINGS		DISTORTION IN INCHES		STRAIN IN INCHES PER LIN.IN		LOAD	
R	L	R	L	R	L	TOTAL	LB.PER SQ. IN
.881	938	.010	.032	.0091	.00291	33140	658.8
.875	.934	.016	.036	.0015	.0033	33510	666.2
.875	.930	.016	.040	.0015	.00364	34270	681.1
.871	.929	.020	.041	.00182	.00373	35400	703.7
.868	926	.023	.044	.0022	.004	36200	719.7
.867	926	.024	044	.0022	.004	37080	737.1
.864	927	.027	.043	00245	.00391	37530	746.1
.861	919	.030	.051	00264	.00464	38270	760.8
.859	.909	.032	.061	.00291	00655	38740	770.2
.848	.907	.043	.063	.00391	.00573	39000	775.1

PLATE V

COLUMN TESTS

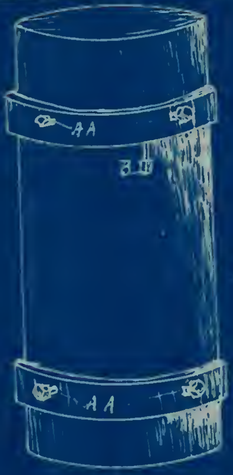


Fig B

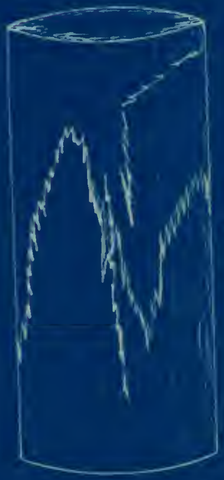


Fig A
SHOWING LINES OF FAILURE

PLATE VI

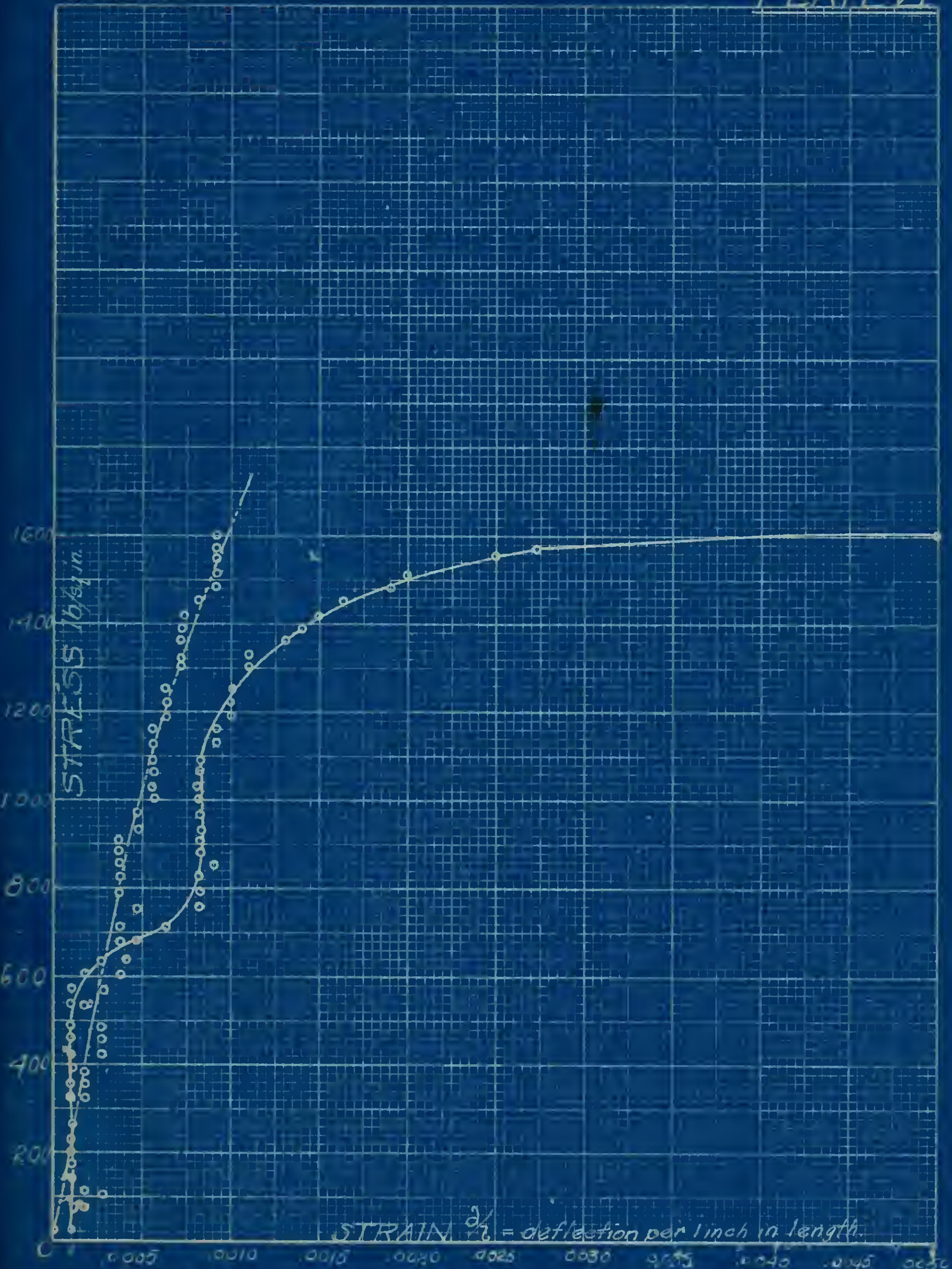
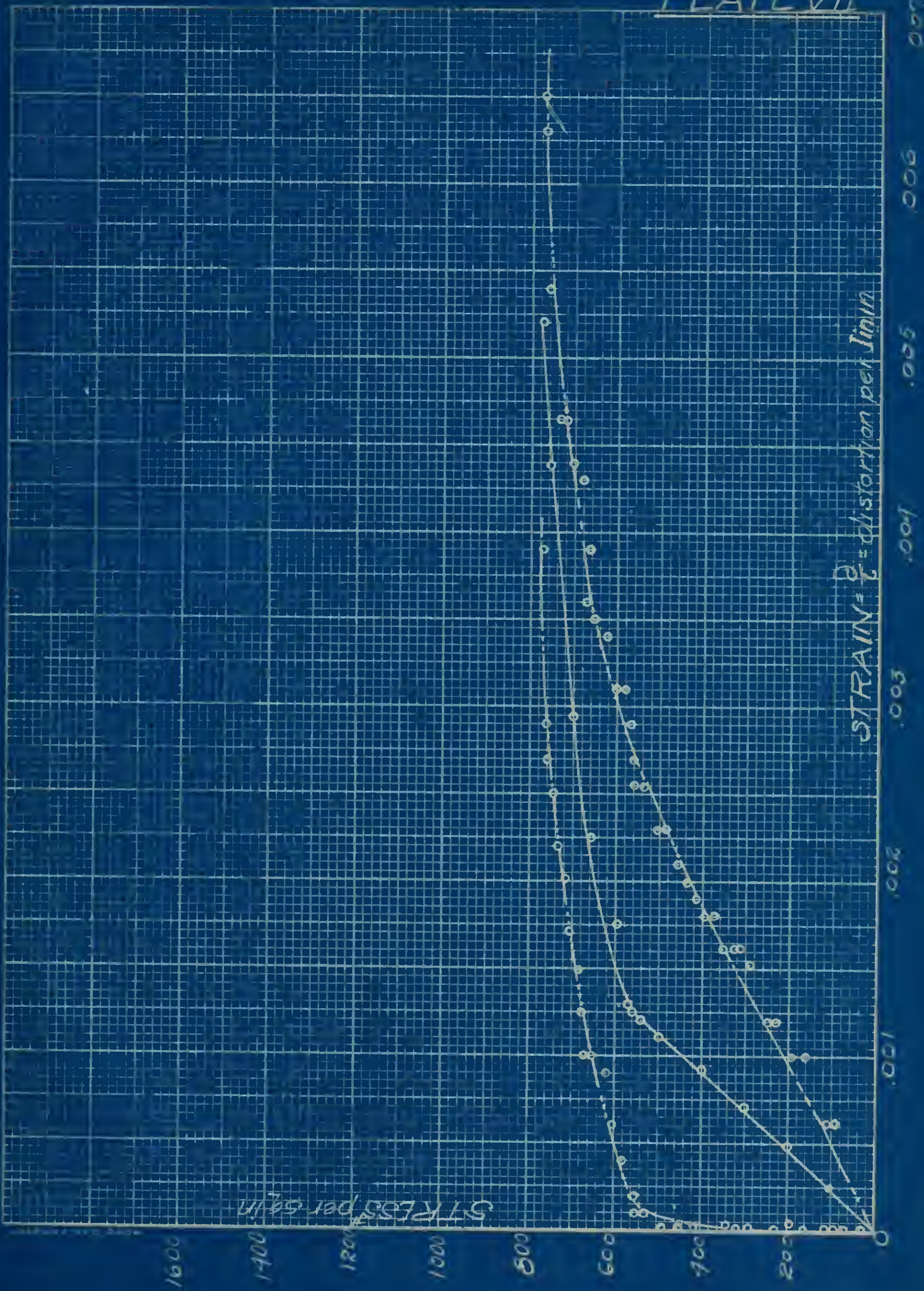

STRESS lb/sq in.
1600
1400
1200
1000
800
600
400
200
0
.0005
.0010
.0015
.0020
.0025
.0030
.0035
.0040
.0045
.0050
STRAIN $\frac{\partial}{l}$ = deflection per 1 inch in length.

PLATE VII



STRAIN = e/l = distortion per l in/in
STRESS per sq in
0
.001
.002
.003
.004
.005
.006
.007
200
400
600
800
1000
1200
1400
1600